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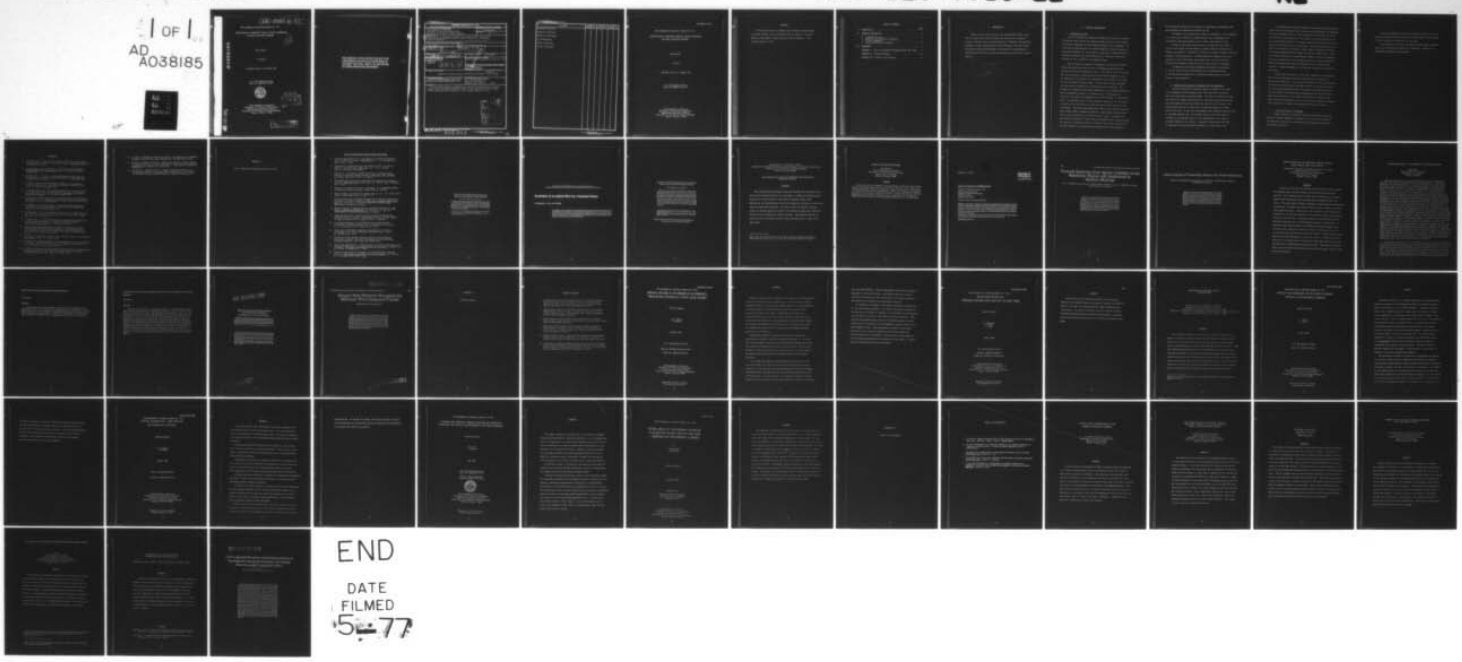

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Electromagnetics Laboratory Report No. 77-4

INVESTIGATION OF INTEGRATED CIRCUITS, OPTICAL PROCESSING, AND RADAR SCATTERING PROBLEMS

(12)

Final Report

R. Mittra

1 February 1974 to 31 January 1977

U.S. Army Research Office
Grant No. DAHC04-74-G-0113

Electromagnetics Laboratory
Department of Electrical Engineering
Engineering Experiment Station
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

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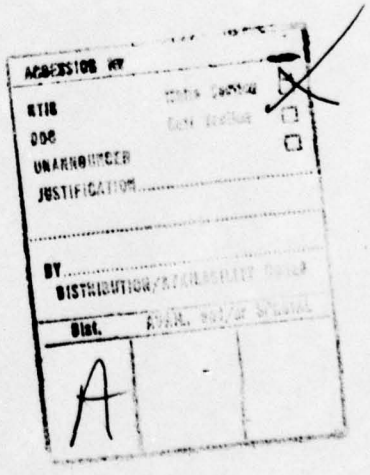

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INVESTIGATION OF INTEGRATED CIRCUITS, OPTICAL PROCESSING, AND RADAR SCATTERING PROBLEMS

Final Report

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1 February 1974 to 31 January 1977

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ABSTRACT

In this final report, we summarize the technical accomplishments in various research areas investigated with the support of the Army Research Grant DAHC04 74-G0113 during the period February 1, 1974 through January 31, 1977.

TABLE OF CONTENTS

I. INTRODUCTION

During the past three years we have investigated a rather broad array of topics that include microwave and quasi-optical integrated circuits, coherent optics and the application of numerical and asymptotic techniques to radar scattering and antenna problems. In the following sections we briefly describe some of the important accomplishments in these areas and list the scientific publications describing the research results.

II. TECHNICAL DESCRIPTION

1. Integrated Circuits

Work on components for microwave integrated circuits was continued from the past grant period with emphasis being placed on the development of efficient techniques for analyzing distributed circuit components. To illustrate the application of the transform method of solution which was previously developed [1], the problem of computing the characteristics of microstrip resonators was investigated and the numerical results were reported [2] for a resonator of rectangular shape.

New directions of research on integrated circuits were initiated during this grant period with a view to bridging the gap between the microwave and optical integrated circuits. This effort led to the development of new concepts in quasi-optical and millimeter waveguides as well as components [3,4] suitable for integrated circuit systems in the 20-90 GHz (or even wider) frequency range. Various types of planar waveguide structures with different types of materials were investigated. The designs that showed the most promise appeared to be the "Inverted Strip", or the IS guide, which consists of a dielectric (ϵ_1) slab mounted on a dielectric (ϵ_2) guide of rectangular cross section resting on a conducting plane. An extensive study of the IS guide was carried out for the choice of quartz for ϵ_1 and teflon for ϵ_2, and the results were found to be very encouraging. Near-field measurements were made to verify that the inverted strip design indeed confines the fields in a region away from the ground plane, a key requirement for reducing conductor losses. Techniques for the theoretical analysis of open dielectric waveguides were developed using the concept of 'equivalent dielectric constant' that allows efficient and accurate analysis of the dominant modes propagating in such waveguides.

The theoretical results were correlated with experimental measurements and good agreement was demonstrated between the two.

In addition to the waveguides a number of integrated circuit components, e.g., directional couplers and resonators, were also investigated, both theoretically and experimentally and the results were reported [5,6].

During the next grant period we plan to investigate yet another form of the IS guide [7] which employs a single dielectric (Stycast Hi-K) design, thus making it convenient for fabrication using, for example, injection molding or etching techniques. Refined methods for analyzing these waveguides will also be developed, particularly with a view to accurately deriving the propagation characteristics in open dielectric waveguides.

In addition to millimeter waveguides, the problem of excitation of optical fibers was also investigated and the optimum dimensions of the system were computed [8] of higher-order modes which are usually present in such waveguides.

2. Numerical and Asymptotic Techniques in Electromagnetics

Extensive research into important aspects of numerical and asymptotic techniques in Electromagnetics has been carried out during the past three years under the present grant. The effect of different testing functions in the moment method solution of thin-wire antenna problems has been investigated [9], and some definitive conclusions with regard to the moment method approach to numerically solving electromagnetic problems have been derived. We have also investigated other anomalous characteristics of the moment method, viz., the unstable nature of the matrix when the frequency of the incident wave is in the neighborhood of the internal resonant frequencies of a scatter. Methods for alleviationg this type of difficulty were developed and described in a journal paper [10].

A new method for solving the problem of scattering from electrically large structures with application to radar scattering problems was developed. The novel technique, called the "Spectral Theory of Diffraction" [11], not only provides a new explanation of the failure of the ray theories at the so-called "trouble-regions," e.g. shadow boundaries and caustics, but shows how these difficulties can be circumvented. The spectral approach is also useful for systematic improvement of high frequency asymptotic solutions as has been demonstrated with a number of practical examples [11] - [13]. This feature, which has not been available hitherto in the ray techniques, opens up new avenues for solving complex problems for which the methods based on the Geometrical Theory of Diffraction are not sufficiently accurate. Further developments of the spectral technique are planned in the future.

Another important problem in the area of numerical electromagnetics that we have investigated involves a monopole antenna situated on a finite ground plane [14]. The current distribution on the ground plane and the antenna itself have been calculated both for the antenna operating in the receiving and transmitting mode. The numerical approach followed in this work differs from conventional techniques and was chosen because it gives stable solutions for the current distribution on structures with edges, whereas the singularity of one of the current components introduces difficulties in the commonly used intregro-differential equations.

3. Digital and Optical Processing

Primary emphasis on research in this area was devoted toward the problem of digital imaging of incoherent sources and to the problem of decoding, deconvoluting or reconstructing these images recorded using a coding aperture [15,16].

Relative advantages of digital processing techniques over their optical counterparts have been pointed out, particularly from the point of view of reducing the distortion in the image.

The problem of correcting the image aberration using a coherent optical data processing technique and a holographic technique for deblurring the image has been reported.

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3. W. McLevige, T. Itoh, and R. Mittra,"New Waveguide Structures for Millimeter Wave and Optical Integrated Circuits," IEEE Trans. MTT, October 1975, pp. 788-794.

4. R. Mittra, "Quasi-optical Millimeter Waveguides and Components", Conference Proceedings of 6th European Microwave Conference, Rome, Italy, pp. 228-229, September 1976.

5. R. Rudokas and T. Itoh, "Passive Millimeter-Wave IC Components Made of Inverted Strip Dielectric Waveguides" IEEE Trans. on Microwave Theory and Techniques, pp. 978-981, December 1976.

6. Tatsuo Itoh, "Inverted Strip Dielectric Waveguide for Millimeter-Wave Integrated Circuits", IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-24, No. 11, November 1976.

7. R. Menendez, N. Deo and R. Mittra, "Experimental and Theoretical Investigations of the Homogeneous Inverted Strip MILIC Dielectric Waveguide", MTT Conference Paper, 1977.

8. M. Mostafavi, T. Itoh and R. Mittra, "Excitation of Guided Modes and the Radiation Field of an Optical Fiber by a Gaussian Beam," Appl. Opt., Vol. 14, pp. 2190-2195.

9. R. Mittra and C. A. Klein, "The Effect of Different Testing Functions in the Moment Method Solution of Thin-Wire Antenna Problems," IEEE Trans. Ant. and Prop., pp. 259-261, March 1975.

10. W.V.T. Rusch, Jorgen Appel-Hansen, Charles A. Klein and R. Mittra, "Forward Scattering from Square Cylinders in the Resonance Region with Application to Aperture Blockage", IEEE Trans. on Antennas and Prop., Vol. AP-24, No. 2, March 1976.

11. R. Mittra, Y. Rahmat-Samii and W. L. Ko, "Spectral Theory of Diffraction", Appl. Phys., 10, pp. 1-13, January 1976.

12. R. Mittra, "A Transform Approach to Electromagnetic Scattering Problems", Proceeding of National Conference on Electromagnetic Scattering, U. of I. at Chicago Circle, pp. 53-55, June 1976.

13. R. Mittra, "A New Look at the Integral Equation Solution of High Frequency Diffraction Problems", Conference Proceedings of the 6th European Microwave Conference, Rome, Italy, pp. 96-97, 1976.

14. R. Mittra, "Antennas on Complex Structures", Proceedings of the ECOM-ARO Workshop on Electrically Small Antennas, pp. 124-128, October 1976.

15. Russell M. Singleton, Preston L. Ransom and R. Mittra, "Digital Imaging of Gamma-Ray Sources with Depth Information", IEEE Trans. on Biomedical Engineering, Vol. BME-23, No. 3, May 1976.

16. R. Mittra, R. Singleton and P. L. Ransom, "Image Reconstruction of Multiple X-ray Sources with Fresnel Zone Plate Apertures", Proceeding '76 ASILOMAR Conference OSA/SPIE Seminar on Image Processing, 1976.

APPENDIX I

List of Publications Sponsored Under This Grant

List of Publications Sponsored Under This Grant

1. "Spectral Domain Approach for Calculating the Dispersion Characteristics of Microstrip Lines," IEEE, MTT-21, No. 7, pp. 496-499, July 1973, (with T. Itoh).

2. "Excitation of Guided Modes and the Radiation Field of an Optical Fiber by a Gaussian Beam," Appl. Opt., Vol. 14, pp. 2190-95 (with T. Itoh and M. Mostafavi).

3. "The Effect of Different Testing Functions in the Moment Method Solution of Thin-Wire Antenna Problems," IEEE Trans. Ant. and Prop. pp. 259-61, March 1975, (with C. A. Klein).

4. "New Waveguide Structures for Millimeter Wave and Optical Integrated Circuits", IEEE Trans. MTT, October 1975, pp. 788-94, (with W. McLevige and T. Itoh).

5. "Antennas on Complex Structures", Proceedings of the ECOM-ARO Workshop on Electrically Small Antennas, October 1976, pp. 124-128.

6. "Spectral Theory of Diffraction", Appl. Phys. 10, pp. 1-13, January 1976 (with Y. Rahmat-Samii and W. L. Ko).

7. "Forward Scattering from Square Cylinders in the Resonance Region with Application to Aperture Blockage", IEEE Trans. on Antennas and Propagation, Vol. AP-24, No. 2, March 1976 (with W.V.T. Rusch, Jorgen Appel-Hansen and Charles A. Klein).

8. "Digital Imaging of Gamma-Ray Sources with Depth Information", IEEE Trans. on Biomedical Engineering, Vol. BMS-23, No. 3, May 1976 (with Russell M. Singleton and Preston L. Ransom).

9. "Image Reconstruction of Multiple X-ray Sources with Fresnel Zone Plate Apertures", Proceeding '76 ASILOMAR Conference OSA/SPIE Seminar on Image Processing (with R. Singleton and P. L. Ransom).

10. "A Transform Approach to Electromagnetic Scattering Problems", Proceedings of National Conference on Electromagnetics Scattering, U. of I. at Chicago Circle, June 1976, pp. 53-55.

11. "Quasi-optical Millimeter Waveguides and Components", Conference Proceedings of 6th European Microwave Conference, Rome, Italy, pp. 228-229, Sept. 1976.

12. "A New Look at the Integral Equation Solution of High Frequency Diffraction Problems", Conference Proceedings of the 6th European Microwave Conference, Rome, Italy, pp. 96-97 (1976).

13. "Passive Millimeter-Wave IC Components Made of Inverted Strip Dielectric Waveguides" IEEE Trans. on Microwave Theory and Techniques, December 1976, pp. 978-981 (R. Rudokas and T. Itoh).

14. "Inverted Strip Dielectric Waveguide for Millimeter-Wave Integrated Circuits", IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-24, No. 11, November 1976 (Tatsuo Itoh).

Spectral-Domain Approach for Calculating the Dispersion Characteristics of Microstrip Lines

TATSUO ITOH AND RAJ MITTRA

***Abstract*—The boundary value problem associated with the open microstrip line structure is formulated in terms of a rigorous, hybird-mode representation. The resulting equations are subsequently transformed, via the application of Galerkin's method in the spectral domain, to yield a characteristic equation for the dispersion properties of the open microstrip line.**

Manuscript received November 29, 1972; revised January 25, 1974. This work was supported in part by the United States Army Research Grant DA-ADO-D-31-71-G77 and in part by NSF Grants GK 33735 and GK 36854.

The authors are with the Department of Electrical Engineering, University of Illinois, Urbana, Ill. 61801.

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Excitation of an optical fiber by a Gaussian beam

M. Mostafavi, T. Itoh, and R. Mittra

In this paper we present the results of an in-depth analysis of the problem of Gaussian beam excitation of optical fibers at normal incidence. The method entails the application of the continuity conditions at the interface located at the fiber end using Gaussian beams with different spot sizes as our excitation source. Next, the simultaneous set of equations obtained is numerically solved for the reflected, guided, and radiated modal coefficients and their corresponding powers.

The Effect of Different Testing Functions in the Moment Method Solution of Thin-Wire Antenna Problems

C. A. KLEIN AND R. MITTRA

Abstract—The use of piecewise sinusoids for expansion functions and rectangular pulses for testing functions is described in the application of the method of moments to thin-wire antennas and scatterers. This choice of expansion and testing functions allows efficient calculation of matrix elements and yields accurate results for certain widths of the testing function. However, for other widths, although the standard criteria for the selection of these functions are satisfied, erroneous results are obtained. The validity of the moment method solution can be checked by examining the near-field.

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The authors are with the Electromagnetics Laboratory, Department of Electrical Engineering, University of Illinois at Urbana-Champaign, Urbana, Ill. 61801.

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Urbana, Illinois 61801

New Waveguide Structures for Millimeter Wave and Optical Integrated Circuits

ABSTRACT

Some new dielectric waveguide structures suitable for millimeter wave and optical integrated circuits are presented. A method of analyzing wave propagation in these guides is developed by assuming simple field distribution and approximating the various regions of the guides in terms of effective dielectric constants. The mathematical formulation utilized results in simple eigenvalue equations from which the dispersion characteristics of the waveguides are readily obtained. Experimental results are described and the agreement between theory and experiment is shown to be quite good.

This work was supported in part by Joint Services Electronics Program DAAEC-0259 and in part by U.S. Army Research Grant DAHC04-74-G0113.

ANTENNAS ON COMPLEX STRUCTURES

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SUMMARY

One of the most challenging problems facing the numerical and analytical electromagneticist today is the design of antennas to be mounted on complex structures, such as automobiles, ships and aircrafts. The problem is complicated for at least two reasons. First, the modeling of complex structures is in itself a difficult problem. Second, and perhaps the more important from the user's point of view, is the choice of the type of formulation best suited for the particular geometry under consideration.

Appl. Phys. 10, 1—13 (1976)

Applied Physics

Spectral Theory of Diffraction*

R. Mittra, Y. Rahmat-Samii, and *W. L. Ko*
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Received 5 November 1975/Accepted 2 January 1976

Abstract. In this paper we present an overview of the spectral domain approach for solving a variety of high frequency diffraction problems. We demonstrate via a number of examples that the fields derived from the use of the Spectral Theory of Diffraction (STD) remain uniformly valid for all observation angles, including the shadow boundary, the reflection boundary and the caustic direction where the conventional Geometrical Theory of Diffraction (GTD) breaks down.
Furthermore, we show how the accuracy of STD can be improved and its range extended by combining it with integral equation methods in the spectral domain.

PACS Codes: 84, 42, 10

Forward Scattering from Square Cylinders in the Resonance Region with Application to Aperture Blockage

W. V. T. RUSCH, SENIOR MEMBER, IEEE, JØRGEN APPEL-HANSEN, MEMBER, IEEE, CHARLES A. KLEIN, AND RAJ MITTRA, FELLOW, IEEE

Abstract—The relationship between the induced field ratio (IFR) of a cylinder and aperture blocking of a constant-phase aperture by cylindrical struts is discussed. An analytical technique is presented whereby the IFR of rectangular cylinders can be calculated using the method-of-moments with internal constraint points. An experimental technique using a forward-scattering range is used to measure the IFR's of square and circular cylinders in an anechoic chamber. These experimental results are compared with the theory, and their implications on aperture blocking losses and boresight cross polarization are discussed.

Digital Imaging of Gamma-Ray Sources with Depth Information

RUSSELL M. SINGLETON, STUDENT MEMBER, IEEE, PRESTON L. RANSOM, MEMBER, IEEE, AND RAJ MITTRA, FELLOW, IEEE

Abstract – A digital method for imaging gamma-ray emitting organs recorded through a Fresnel zone plate (FZP) aperture is described. This technique can be used in an almost real-time recording and imaging system to yield quantitative and qualitative cross-section and depth information of the source. Furthermore, this method avoids some of the problems introduced by the usual method of optical reconstruction. Experimental results of the recording of a multiplane gamma-ray source and the reconstruction of digitally and optically formed images are also presented.

IMAGE RECONSTRUCTION OF MULTIPLANE GAMMA-RAY SOURCES WITH A FRESNEL ZONE PLATE APERTURE

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ABSTRACT

A process is described for digitally reconstructing images of gamma-ray emitting organs recorded through an off-axis Fresnel zone plate aperture. This technique produces image cross sections for given depths which contain both quantitative and qualitative information about the source. The practicality of digital decoding is demonstrated experimentally by comparing the digital and optical reconstructions of images of a multiplane gamma-ray source. Specifically, the multiplane source consists of numerals one, two and three located in three distinct planes at successive depths from the detector. The digital method of reconstruction has the following advantages over a method employing optical reconstruction. A quasi-real time system capable of recording and producing images can be assembled using components currently available. Quantitative data such as the source size and depth are readily determined. Digital image processing can be easily implemented to reduce the effect of artifacts and noise. Unlike the case using optical reconstruction, the image depth dimension is not distorted in comparison with the source depth. Nonlinearity and film noise associated with the photographic process of obtaining a reduced transparency are avoided.

A TRANSFORM APPROACH TO ELECTROMAGNETIC SCATTERING PROBLEMS

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Generally speaking, there are two distinctly different approaches available for solving electromagnetic scattering problems. Asymptotic methods, for large wavenumber k, introduced by Keller [1] and developed by a great many researchers [2,3], are usually employed for scatterers whose dimensions are large in terms of the wavelength of the incident field. In this analysis, scattering is considered a local phenomenon, identifiable with specific parts of the object, e.g., specular points, corners, and shadow boundaries. The diffracted far fields are expressed in terms of rays for which the diffraction and launching coefficients are determined by solving canonical problems that closely resemble the surface configuration in the vicinity of the point from which the diffracted field originates. The second approach, based on an integral equation formulation for the unknown surface current on the scatterer, is a global formulation in which the induced current distribution on the entire surface of the scatterer must be solved for before the far field can be constructed. The integral equation has the great advantage of being entirely self-consistent as the boundary condition is already built-in in this approach. The method of solution of the integral equation is typically based on the moment method which transforms the original equation into a matrix form that is numerically inverted on the computer. Though, in principle, the integral equation technique is valid for the entire frequency range, its application is restricted to frequencies below the so-called "resonance region," i.e., when the dimensions of the scatterer are on the order of a wavelength or less. This restriction is necessary because the matrix method of solution becomes very expensive and unwieldy as the frequency is allowed to approach the resonance region. On the other hand, high frequency asymptotic methods typically become quite inaccurate when applied to the lower frequency range. Furthermore, they provide no convenient accuracy checks, and the systematic improvement of these solutions may also be difficult. Thus, there exists a great need for a method which will not only bridge the existing gap between the low and high frequency regions, but will also provide an accuracy check and a systematic improvement procedure for the high asymptotic solutions.

The purpose of this paper is to demonstrate that a recently developed [3] transform method of solution of the integral equation appears to meet all of the desired requirements alluded to above. The application of the Fourier transform technique to the solution of scattering problems is by no means new. The problem of arbitrary incident waves diffracting from a scatterer, e.g., a half-plane has been formulated by Clemmow [4], Felsen and Marcuvitz [5] and Khestanov [6], to name just a few. The Fourier transform technique itself has been employed by Bojarski [7] for solving scattering problems.

QUASI-OPTICAL MILLIMETER WAVEGUIDES AND COMPONENTS

Raj Mittra

ABSTRACT

In this paper we review a number of quasi-optical waveguide structures and discuss their application to millimeter-wave integrated circuits. Some novel designs for dielectric waveguides and passive components using these waveguides are described. A summary of the results of theoretical and experimental studies of these waveguides and circuits is presented.

A NEW LOOK AT THE INTEGRAL EQUATION SOLUTION OF HIGH FREQUENCY DIFFRACTION PROBLEMS

Raj Mittra

ABSTRACT

In this paper we report a transform method for combining the integral equation and high frequency asymptotic techniques, e.g., the geometrical theory of diffraction or GTD. The method takes advantage of the fact that the Fourier transform of the unknown surface current distribution is proportional to the scattered far field. Two methods are developed for systematically improving the initial form of the high frequency asymptotic solution by manipulating the integral equation in the Fourier transform domain. Two salient features of the transform method are that it provides a convenient validity check of the solution and that it yields both the induced surface current density as well as the far field. Several illustrative examples that demonstrate the usefulness of the approach for handling a variety of electromagnetic scattering problems in the resonance region *and* above, and comparison with other methods are included in this paper.

Passive Millimeter-Wave IC Components Made of Inverted Strip Dielectric Waveguides

R. RUDOKAS AND T. ITOH, SENIOR MEMBER, IEEE

Abstract—New directional couplers and ring resonators for millimeter-wave IC's were fabricated from the inverted strip (IS) dielectric waveguide. They were tested in the 75-80-GHz range, and the agreement between the theoretical and experimental results was found to be good.

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T. Itoh was with the Coordinated Science Laboratory and the Department of Electrical Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801. He is now with the Stanford Research Institute, Menlo Park, CA 94025.

Inverted Strip Dielectric Waveguide for Millimeter-Wave Integrated Circuits

TATSUO ITOH, SENIOR MEMBER, IEEE

***Abstract*—A new type of dielectric waveguide, which has a number of advantages over other previously available waveguide structures for millimeter-wave integrated circuits, is described. Dispersion characteristics and the field distributions in the waveguide are calculated using the concept of effective dielectric constant. Field distributions have been measured in the 80-GHz range in order to check the accuracy of the analytical results. This measurement has been done using a novel experimental technique, which should also be applicable to many other millimeter-wave waveguides and components.**

APPENDIX II

Technical Reports

Technical Reports

1. "Numerical Solutions to the Problems of Electromagnetic Radiation and Scattering by a Finite Hollow Cylinder," Technical Report, Antenna Lab. Report No. 74-10 (with W. A. Davis) October, 1974, Contract DA-ARO-D-31-124-71-G77 and DAHCO4-74-G-0113.

2. "An Efficient Method for Performing Karhunen-Loeve Transform for Image Coding," Technical Report, Antenna Lab. Report No. 74-12, (with D. Setoguchi and T. Itoh) August, 1974, Contract DA-ARO-D-31-124-71-G77 and DAHCO4-74-G-0113.

3. "Excitation of an Optical Fiber by a Gaussian Beam," Technical Report, Antenna Lab. Report No. 74-16 (with M. Mostafavi and T. Itoh) 1974, Contract DAHCO4-74-G-0113.

4. "Stability and Convergence of the Method of Moments Applied to Electromagnetic Problems," Technical Report, EM Lab. Report No. 75-1, (with C. A. Klein) January 1975, Contract DA-ARO-D-31-124-71-G77 and DAHCO4-74-G-0113.

5. "Digital Deconvolution: Image Sampling and Restoration Techniques" Technical Report, EM Lab. Report No. 75-5 (with D. J. Udovic), October 1975, Contract DA-ARO-D-31-124-71-G77 and DAHCO4-74-G-0113.

6. "A Method for Combining Integral Equation and Asymptotic Techniques for Solving Electromagnetic Scattering Problems", Ko - Ph.D. Thesis (Mittra GO113), Technical Report; EM Lab. Report No. 76-6, May 1976, Contract DA-ARO-D-31-124-71-G77 and DAHCO4-74-G-0113.

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Electromagnetics Laboratory Report No. 74-10

NUMERICAL SOLUTIONS TO THE PROBLEMS OF ELECTROMAGNETIC RADIATION AND SCATTERING BY A FINITE HOLLOW CYLINDER

Technical Report

W. A. Davis
R. Mittra

October 1974

U.S. Army Research Office

Grant No. DA-ARO-D-31-124-71-G77

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Electromagnetics Laboratory
Department of Electrical Engineering
Engineering Experiment Station
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ABSTRACT

Numerical techniques for solutions to the problems of electromagnetic radiation and scattering are considered for a finite, hollow, circular cylinder of radius a. The singular-integral equations of electromagnetic scattering theory are derived along with their extensions to thin surfaces and surfaces with edges. In addition, constraints are presented which are necessary for a unique solution to the scattering problems of thin structures. The equations for a finite hollow cylinder are obtained by expanding the field quantities in Fourier series about the cylinder axis giving rise to a separate set of singular integral equations for each harmonic.

The method of moments is presented as the basic technique of digitizing the integral equations for numerical solution. It is found that the variational interpretation of the method of moments can be used as a guide for choosing the basis and testing functions. Of particular interest as basis functions are the spline functions of finite support. The spline function properties of smoothness and best fit are also presented.

It is shown that Hallen's and Pocklington's formulations for the thin wire problem are equivalent numerically for appropriate testing functions. It is also shown that the Pocklington form is more desirable when smooth basis functions are used in conjunction with pulse or delta testing functions. In this context, the second-order sinusoidal spline is found to be an excellent current representation for both the scattering

and pulse-feed problems. Slope discontinuities are easily included to approximate a delta-feed problem. Approximate operators are also considered with emphasis on the equivalence of the finite difference approximation and piecewise sinusoidal basis functions.

The problems of coupling in the higher harmonics are investigated for the first-harmonic problem. It is shown that minimum coupling of the equations is desirable in addition to the dominance of each equation over the entire structure by its respective current component. These features are obtained using a new set of equations obtained from the combination of the equations for the tangential electric field and the normal magnetic field. These equations are related to the normal derivative of the tangential magnetic field equations which are well-behaved for thick structures. The solutions of these equations are in excellent agreement with the results of other workers. Various operator approximations are also considered.

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Electromagnetics Laboratory Report No. 74-12

AN EFFICIENT METHOD FOR PERFORMING KARHUNEN-LOEVE TRANSFORM FOR IMAGE CODING

Technical Report

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ABSTRACT

An efficient method has been developed for performing the Karhunen-Loeve transform which is optimum for reducing the number of samples to be sent via a given channel for high fidelity picture transmission. The method is based on the use of the Fast Fourier Transform algorithm and linear interpolation procedure. Some test computations illustrating the use of the method are included in the paper.

EXCITATION OF AN OPTICAL FIBER BY A GAUSSIAN BEAM

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ABSTRACT

In this paper we present the results of an in-depth analysis of the problem of Gaussian beam excitation of optical fibers at normal incidence. The first step involves the derivation of the eigenvalues and eigenfunctions of the guided modes as well as the radiation field of the fiber. Then, the eigenvalue equation is solved for the frequencies of interest using numerical techniques. The second step entails the application of the continuity conditions at the interface located at the fiber end using Gaussian beams with different spot sizes as our excitation source. Next, the simultaneous set of equations obtained is numerically solved for the reflected, guided and radiated modal coefficients and their corresponding powers.

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Electromagnetics Laboratory Report No. 75-1

STABILITY AND CONVERGENCE OF THE METHOD OF MOMENTS APPLIED TO ELECTROMAGNETIC PROBLEMS

Technical Report

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ABSTRACT

The method of moments is a simple technique for converting integral equations occurring in electromagnetics problems into matrix equations which can be easily solved on digital computers. Although the method of moments can be readily applied to a wide class of problems, it should not be assumed that the computed results automatically converge to the correct solution. One of the difficulties that can occur is an instability of the method to small, unavoidable errors. To measure this possible ill-conditioning, stability parameters are discussed. The primary parameter used will be the matrix condition number, a scalar function of the matrix, which is useful in estimating errors in the calculated solution due to errors in either the matrix or the excitation vector. The a posteriori condition number provides an improved estimate by considering the particular excitation vector. The pivot ratio has definite computational advantages. Several methods for improving the stability of the matrix equation are compared.

The discussion and theory of stability and convergence are applied to six areas of applications — waveguide discontinuities, wavefront reconstruction, electrostatics, remote sensing, scattering by rectangular conducting cylinders, and thin-wire antennas and scatterers. The chapters on these applications not only demonstrate the theory but also discuss other investigations of the method-of-moments technique. The best method for calculating Induced Field Ratios, a useful parameter in describing scattering by rectangular cylinders, is presented. A new application of

the method of moments to thin-wire modeling of antennas, which is using piecewise sinusoids and rectangular pulses as modeling functions, is compared with the reaction-matching technique. The surprising equivalence between finite differencing and the use of sinusoids with pulses is discussed. Also studied are antennas with junctions and straight antennas modeled with unequal length segments.

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Electromagnetics Laboratory Report No. 75-5

DIGITAL DECONVOLUTION: IMAGE SAMPLING AND RESTORATION TECHNIQUES

Technical Report

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ABSTRACT

The finite length digital deconvolution problem is formulated and discussed in terms of modern optimization theory. The ill-conditioned nature of deconvolution is identified and classic deconvolution operators are examined in terms of their respective effectiveness and ease of implementation.

Continuous deconvolution filters that are optimal in terms of minimum variance and solution smoothness are derived. These filters contain digital counterparts which can be obtained by means of conventional frequency sampling techniques.

Quantization and frequency-aliasing are identified as characteristic noise sources of digital deconvolution and analyzed in terms of their respective corrupting effects upon accurate optical signal estimation. Three approaches for eliminating frequency-aliasing error are discussed.

A multiple intensity measurement technique for determining the magnitude and phase of complex optical wavefronts by means of a coherent optics-microprocessor hybrid system is developed.

A picture-shift sampling scheme is proposed for effectively increasing picture sampling resolution without requiring additional computer core. A method is developed, based upon this scheme and incoherent light illumination, for performing continuous low-pass filtering. A noise analysis of the sampling technique is later performed.

Linear system testing is discussed in terms of its role with respect to digital deconvolution processing. Test accuracy requirements are formulated to guarantee the possibility of successful deconvolution algorithm

implementation. An optimal test signal and testing strategy for linear system measurement are analytically derived by maximizing the probability of acceptable deconvolution estimation.

Electromagnetics Laboratory Report No. 76-6

A METHOD FOR COMBINING INTEGRAL EQUATION AND ASYMPTOTIC TECHNIQUES FOR SOLVING ELECTROMAGNETIC SCATTERING PROBLEMS

Technical Report

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ABSTRACT

This paper introduces a new approach for combining the integral equation and high frequency asymptotic techniques, e.g., the geometrical theory of diffraction. The method takes advantage of the fact that the Fourier transform of the unknown surface current distribution is proportional to the scattered far field. A number of asymptotic methods are currently available that provide good approximation to this far field in a convenient analytic form which is useful for deriving an initial estimate of the Fourier transform of the current distribution.

An iterative scheme is developed for systematically improving the initial form of the high frequency asymptotic solution by manipulating the integral equation in the Fourier transform domain.

A synthetic-aperture-distribution scheme is also developed in which the approximate scattered far-field pattern obtained by asymptotic techniques is improved by systematically correcting the scattered field distribution on an aperture erected in juxtaposition with the obstacle. The introduction of such a planar aperture not only provides an additional degree of freedom in performing improving operations, but also renders the scheme to handle n-dimensional geometries by (n - 1)-dimensional fast Fourier transform (FFT), where n = 2,3, and circumvents the unwieldy three-dimensional FFT, making it a conceptually simple and computationally efficient method.

UILU-76-2560

Electromagnetics Laboratory Report No. 76-10

SPECTRAL ANALYSIS OF HIGH-FREQUENCY DIFFRACTION OF AN ARBITRARY INCIDENT FIELD BY A HALF-PLANE — COMPARISON WITH FOUR ASYMPTOTIC TECHNIQUES

by

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Technical Report

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ABSTRACT

The knowledge of high-frequency diffraction of an arbitrary wave incident on an edge is important in many applications, such as antennas mounted on aircraft and reflector antennas illuminated by complex feeds. In this paper the problem of a half-plane illuminated by a nonplanar wave is investigated using the concept of the plane wave spectral representation. For large wave number k, a new higher-order asymptotic solution for the total field up to and including terms of order $k^{-5/2}$ relative to the incident field is derived. The behavior of the solution for the observation points which coincide with shadow boundary directions of a multipole line source is discussed in detail. Furthermore, numerical solution of the field integral representation is constructed for the observation angles in the transition regions. The results are compared with those of the Geometrical Theory of Diffraction (GTD), the Uniform Asymptotic Theory (UAT), the Uniform Theory of Diffraction (UTD) and the Modified Slope Diffraction (MSD).

APPENDIX III:

Papers to be Published

Papers to be Published

1. "A spectral domain interpretation of high frequency diffraction phenomena." IEEE Trans. and Prop., AP-S, (with Y. Rahmat-Samii).

2. "On the investigation of diffracted fields at the shadow boundaries of staggered parallel plates - a spectral domain approach", (with Y. Rahmat-Samii).

3. "An approach to high-frequency scattering from smooth convex surfaces" IEEE Trans. AP-S, (with W. L. Ko).

4. "A new approach to the thin scatterer problem using the hybrid equations" IEEE Trans. AP-S, (with W. A. Davis).

5. "A new approach based on a combination of integral equation and asymptotic techniques for solving electromagnetic scattering problems", IEEE AP-S, (with W. L. Ko).

A SPECTRAL DOMAIN INTERPRETATION OF HIGH FREQUENCY DIFFRACTION PHENOMENA

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ABSTRACT

A spectral domain interpretation of high frequency diffraction phenomena is discussed introducing the concept of a spectral diffraction coefficient which resembles Keller's coefficient. The solution of the two-dimensional problems of diffraction of an arbitrary field (with no caustics) by a half-plane is investigated and results are given for any observation angle including, in particular, the determination of the field at the shadow boundaries. The high frequency scalar diffraction by apertures and semi-infinite cylinders is formulated in a systematic manner and the formulation, which is valid for any observation angle, is compared with that of Ufimtsev's. Results are also given for the diffracted field at the caustics.

ON THE INVESTIGATION OF DIFFRACTED FIELDS AT THE SHADOW BOUNDARIES OF STAGGERED PARALLEL PLATES--A SPECTRAL DOMAIN APPROACH

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ABSTRACT

The diffraction of plane waves by two staggered parallel plates is investigated using the spectral diffraction coefficient in the Fourier transform domain. It is shown that when the interaction between the plates is negligible, the total field can be represented in terms of a double Fourier integral, a result that is identical to the one derived by Jones via the Weiner-Hopf technique. The double integral is asymptotically evaluated via the saddle-point integration technique and compact expressions for the field are derived, up to the order k^{-1}, for observation points located at the shadow boundaries and also away from the transition regions. These expressions, being exact, serve a very useful purpose, viz., they are used to test different uniform and nonuniform asymptotic theories at the shadow boundaries. The results of these tests are included in the paper.

A SPECTRAL DOMAIN METHOD FOR REMOTELY PROBING STRATIFIED MEDIA

ABSTRACT

The problem of remotely probing a stratified, lossless, dielectric medium is formulated using the spectral domain method of probing. The response of the medium to a spectrum of plane waves incident at various angles is used to invert the unknown profile. For TE polarization, the electric field satisfies a Helmholtz equation. The inverse problem is solved by means of a new representation for the wave function. The principal step in this inversion is solving a second kind Fredholm equation which is very amenable to numerical computations. Several examples are presented including some which indicate that the method can be used with experimentally obtained data. When the fields exhibit a surface wave behavior, a unique inversion can be obtained only if information about the magnetic field is also available. In this case, the inversion is accomplished by a two-step procedure which employs a formula of Jost and Kohn. Some examples are presented and an approach which greatly shortens the computations without greatly deteriorating the results is discussed.

TRANSMISSION OF AN EM WAVE THROUGH THE APERTURE OF A CYLINDRICAL CAVITY*

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ABSTRACT

The penetration of an electromagnetic wave through an aperture in a cylindrical structure is investigated. By using the moment method, the electrical and magnetic fields in a cavity behind the aperture are determined as a function of frequency of the incident field. The accuracy of the numerical solution is established through tests of satisfaction of the boundary condition, edge condition, and convergence with respect to the number of modes in the aperture. Depending on the frequency and location inside the cavity, the stored electromagnetic energy density varies very rapidly. Its peak value can be two orders of magnitude greater than the incident energy density. The frequencies where the peaks occur can be identified approximately as the resonance frequencies of the cavity when the aperture is closed.

AN APPROACH TO HIGH-FREQUENCY SCATTERING FROM SMOOTH CONVEX SURFACES

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ABSTRACT

In this paper we introduce a method based on the Galerkin procedure in the transform domain that not only allows accurate solutions for both the far-field and the induced surface current be derived but also provides a convenient accuracy check for the solutions thus obtained. The total solution is constructed using only the geometrical optics method and a newly introduced synthetic aperture technique well suited for deriving efficient transform solutions for n-dimensional, smooth curved objects using (n - 1) - dimensional transforms. The need for the conventional creeping-wave contribution is obviated in this method.

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A NEW APPROACH TO THE THIN SCATTERER PROBLEM USING THE HYBRID EQUATIONS

William A. Davis, Member, IEEE, and Raj Mittra, Fellow, IEEE

ABSTRACT

A new set of integral equations for electromagnetic scattering problems, the "hybrid" equations, are presented. The advantages of these equations for thin perfect conductors are discussed in comparison to the magnetic and electric field integral equations. Specific comparisons are made with the solution of the electric field integral equation for a finite hollow cylinder. It is demonstrated that the primary advantage of these equations is obtained by minimizing the coupling between component equations for the two surface currents.

Authors

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A New Approach Based on a Combination of Integral Equation and Asymptotic Techniques for Solving Electromagnetic Scattering Problems

WAI LEE KO AND RAJ MITTRA, FELLOW, IEEE

Abstract—We introduce a new approach for combining the integral equation and high frequency asymptotic techniques, e.g., the geometrical theory of diffraction. The method takes advantage of the fact that the Fourier transform of the unknown surface current distribution is proportional to the scattered far-field. A number of asymptotic methods are currently available that provide good approximation to this far-field in a convenient analytic form which is useful for deriving an initial estimate of the Fourier transform of the current distribution. An iterative scheme is developed for systematically improving the initial form of the high frequency asymptotic solution by manipulating the integral equation in the Fourier transform domain. A salient feature of the method is that it provides a convenient validity check of the solution for the surface current distribution by verifying that the scattered field it radiates indeed satisfies the boundary conditions at the surface of the scatterer. Another important feature of the method is that it yields both the induced surface current density *and* the far-field. Diffraction by a strip (two-dimensional problem) and diffraction by a thin plate (three-dimensional problem) are presented as illustrative examples that demonstrate the usefulness of the approach for handling a variety of electromagnetic scattering problems in the resonance region *and* above. Some concluding remarks and comparison with other methods are also included.